

# Charged particle multiplicity and Transverse energy distribution using Weibull-Glauber approach in Heavy-Ion collisions.

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The charged particle multiplicity distribution and the transverse energy distribution measured in heavy-ion collisions at top RHIC and LHC energies are described using the two-component model approach based on convolution of Monte Carlo Glauber model with the Weibull model for particle production. The model successfully describes the multiplicity and transverse energy distribution of minimum bias collision data for a wide range of energies. We also propose that Weibull-Glauber model can be used to determine the centrality classes in heavy-ion collision as an alternative to the conventional Negative Binomial distribution for particle production.

## I. INTRODUCTION

The charged particle multiplicity distribution is regarded as one of the basic global observable, which has been most widely measured and studied to understand the particle production mechanism in the hot and dense matter created in ultra-relativistic nucleus-nucleus collisions. Similarly, the transverse energy distribution of produced particles is treated as another global observable and is well suited for probing the QCD medium. Both the observables are connected to the collision geometry, the entropy and initial energy density of the system created in heavy-ion collisions [1–3]. Various experimental measurements suggest that charged particle pseudorapidity density can be successfully used to study the expansion dynamics by Landau hydrodynamics [2, 4–7]. Similarly, transverse energy can be used for understanding the longitudinal expansion of the system in the midrapidity and is subjected to the Bjorken hydrodynamics [3, 5]. This establishes a correlation between them and their measurements compliment each other to put constraints on the collision dynamics. The linear correlation between the mean charged particle multiplicity and the mean transverse energy suggests further the apparent equivalence. Hence, both of these observables are usually the first measurements done in heavy-ion collision experiments as global observables to study the underlying reaction mechanism for particle production and characterizing the collision system. In view of this, it is very crucial to understand the charged particle

multiplicity and the transverse energy distribution measured in heavy-ion collisions.

Before understanding a complex system like nucleus-nucleus collision, it is customary to understand the particle production mechanism in nucleon-nucleon collisions. Recently, the Weibull model of particle production based on the fragmentation and sequential branching mechanism have been very successful in describing the overall feature of multiparticle production in hadronic and leptonic collisions [8, 9]. Previously, it was emphasized that the main features of multiplicity distribution in nucleus nucleus collisions were just a consequence of the initial geometry of the collisions. As the nuclei are extended objects, the interaction volume depends on impact parameter of the collision system. However, it is impossible to measure the impact parameter of the collision directly in experiments. Experimentally, these quantities are estimated by observing the number of particles or the transverse energy of the produced particles in the collision. To establish the one-to-one correspondence between the geometrical quantities, like impact parameter with measured charged particle multiplicity, a Monte Carlo (MC) based Glauber model is widely used. In the Glauber MC model [10, 11], a nuclear collision (in p–A and A–A systems) is modelled as a superposition of individual nucleon-nucleon interactions [12]. The initial overlap volume of two colliding nuclei can be expressed in terms of the number of wounded nucleons (nucleons who have undergone one or more binary collisions). The number of such nucleons are known as number of participant nucleons,  $N_{part}$ . The number of binary collisions ( $N_{coll}$ ) among the nucleons depends on inelastic nucleon-nucleon cross section ( $\sigma_{NN}^{inel}$ ). So by using the Glauber MC model,

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both these quantities are calculated for a Woods-Saxon type of initial nuclear density distribution for a given value of the impact parameter. This geometrical approach helps to provide a consistent description of nuclear collisions in different systems (p-A, d-A, and A-A) when comparing different experimental to theoretical calculations [13–17].

In this work, we have used the two component approach based on Glauber model, combined with the Weibull model of multiparticle production in hadronic interaction to simulate the multiplicity distribution in heavy-ion collisions. The obtained distribution is compared to the experimental data measured at RHIC and LHC energies. The Weibull-Glauber approach is similar to the fitting procedure adopted by ALICE experiment for the centrality determination in Pb-Pb collisions at 2.76 TeV and 5.02 TeV using the Negative Binomial distribution [13, 14]. We have also implemented the same formalism to describe the transverse energy distribution in heavy-ion collisions. We also compare our results with HIJING simulation results to validate our model and the proposal for determining the centrality classes of heavy-ion collision.

## II. THE MODEL

The simple model aims to describe the qualitative features of the charged particle multiplicity and transverse energy distribution in heavy-ion collision. In nucleus-nucleus collision, each of the wounded constituents, gives rise to an ancestor which then fragments into the final state hadrons. The Monte Carlo Glauber model [10, 11] is used to simulate the collision process of two nuclei on an event-by-event basis. The position of the nucleons inside the nucleus is determined by the nuclear density function, modeled by the available functional forms (Fermi function, Hulthén form, Woods-Saxon, Uniform etc). The impact parameter is chosen randomly and the maximum value of the impact parameter is mostly close to twice of the radius of the nucleus. The collision of two nuclei is treated as individual and independent collision of the nucleons, where the nucleons travel undeflected in a straight line path. The inelastic cross-section,  $\sigma_{NN}^{inel}$  is treated to be independent of the number of collisions a nucleon underwent previously. The value of  $\sigma_{NN}^{inel}$  is given as another input for the MC Glauber model, which depends on the collision energy as used by various experiments [10, 13, 16]. The Glauber MC model provides the number of

participant,  $N_{part}$ , and the number of binary collisions,  $N_{coll}$ , for an event with a given impact parameter and collision energy. To determine the particle multiplicity for a single event, one defines the number of independent sources emitting particles, also known as ‘ancestors’ [13]. The number of ancestors can be parametrized by assuming suitable dependence on  $N_{part}$  and  $N_{coll}$  as the final multiplicity of an event depends on the impact parameter of the collision. The event multiplicity (or transverse energy) is expected to scale with  $N_{part}$  where the particle production is dominated by soft processes while the  $N_{coll}$  scaling is observed where hard processes dominate over soft particle production [18, 19]. We have assumed a two-component approach [13] where the number of ancestors have been parametrized in terms of both  $N_{part}$  and  $N_{coll}$  as the following

$$N_{ancestors} = xN_{part} + (1 - x)N_{coll} . \quad (1)$$

The aforementioned dependence takes care of the relative contribution ( $x$ ) of both hard and soft processes in the final multiplicity. The approach as described by Eq.1 in convolution with negative binomial distribution (NBD) has been very successful in describing the charged particle multiplicity densities at RHIC and LHC energies [13]. But in our model, the charged particle multiplicity per nucleon-nucleon collisions is parametrized by the Weibull distribution. This latter assumption is motivated by the fact that in minimum bias  $pp$  ( $p\bar{p}$ ) collisions, the charged particle multiplicity distribution is better described by the Weibull function than the NBD for a wide range of energies [8, 9]. Thus, it validates the choice of Weibull function over the traditional NBD.

The probability of producing  $n$  particles per ancestor is given by the two parameter Weibull distribution

$$P(n; \lambda, k) = \frac{k}{\lambda} \left( \frac{n}{\lambda} \right)^{k-1} e^{-\left(\frac{n}{\lambda}\right)^k}, \quad (2)$$

where  $\lambda$  is related to the mean multiplicity per ancestor and  $k$  is related to the production dynamics. For each event, the Weibull distribution is randomly sampled for  $N_{ancestors}$  times to obtain the number of particles produced in that event. The process is repeated for various values of  $\lambda$ ,  $k$  and the two-component parameter  $x$  to simulate an experimental multiplicity (or transverse energy) distribution, which can be compared with measured experimental data.

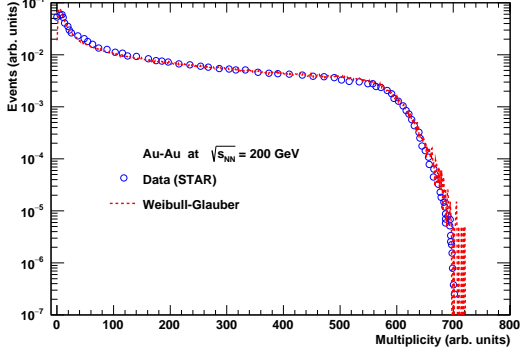


FIG. 1. (Color online) The charged particle multiplicity distribution measured by the STAR TPC detector in  $|\eta| < 0.5$  for Au–Au collisions at  $\sqrt{s_{NN}} = 200$  GeV [21]. They are represented by open circles. The distribution is compared with the Weibull-Glauber model results shown by star markers.

### III. RESULTS

The method was used to describe the charged particle multiplicity and transverse energy distribution measured by various experimental facilities at RHIC and LHC energies. The model fit to the charged particle multiplicity distribution measured in the mid-rapidity in Au–Au collisions at  $\sqrt{s_{NN}} = 200$  GeV by STAR TPC detector [21] is shown in Figure 1. In ALICE experiment, the amplitude of VZERO detector is proportional to the charged particle multiplicity. Therefore, we fit our model with the VZERO detector amplitude measured in Pb–Pb collisions at  $\sqrt{s_{NN}} = 2.76$  TeV by ALICE experiment [13], which is shown in Figure 2. It can be seen from Figure 1 and Figure 2 that the distributions obtained from the above model successfully describes the charged particle multiplicity distribution in Au–Au and Pb–Pb collisions at  $\sqrt{s_{NN}} = 200$  GeV and 2.76 TeV, respectively.

We also fit our model to the minimum-bias transverse energy distribution measured by PHENIX experiment in Au–Au collisions at  $\sqrt{s_{NN}} = 200$  GeV as shown in Figure 3 [22]. Recently, the transverse energy distribution was also measured by ALICE experiment for Pb–Pb collisions at  $\sqrt{s_{NN}} = 2.76$  TeV [23]. Figure 4 compares the  $E_T$  distribution generated by our model with that obtained in Pb–Pb collisions at 2.76 TeV. From the above comparisons, one can observe that the two-component Weibull-Glauber approach provides an excellent description of the measured minimum bias data for charged particle

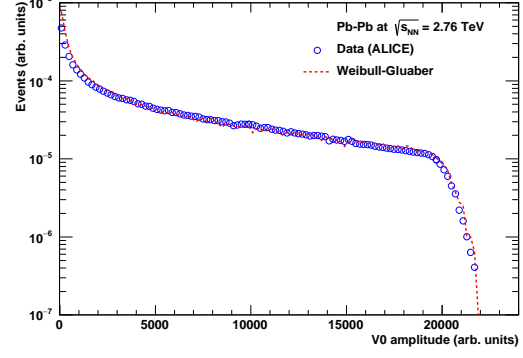


FIG. 2. (Color online) The distribution of the sum of amplitudes in the VZERO scintillators in Pb–Pb collisions at  $\sqrt{s_{NN}} = 2.76$  TeV [13] shown by open circle. The distribution is compared with the Weibull-Glauber model (as discussed in the text) shown by star markers.

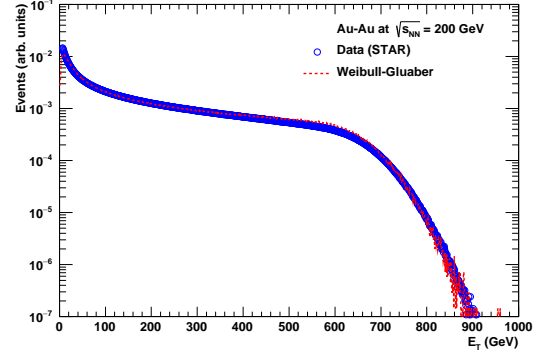


FIG. 3. (Color online) The open circle represents the transverse energy recorded in mid-rapidity by PHENIX lead-scintillator detector in minimum bias Au–Au collision events at  $\sqrt{s_{NN}} = 200$  GeV [22]. The data is compared with Weibull-Glauber model shown by star markers.

multiplicity and transverse energy distribution.

### IV. DETERMINING CENTRALITY CLASSES

The experimental charged particle multiplicity distribution can be divided into different classes of geometrical collision by defining sharp cuts in multiplicity or any other suitable detector variable to define the same. These centrality classes also define the intervals of hadronic cross-section. So it is very important to determine the correct central-

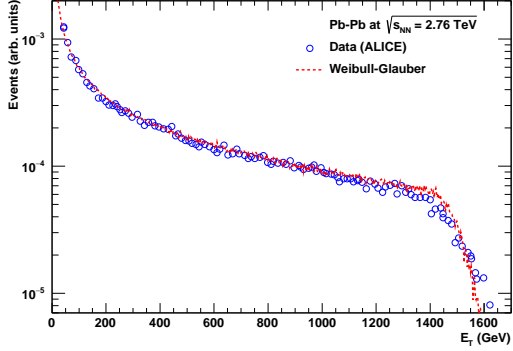


FIG. 4. (Color online) Midrapidity transverse energy distribution of minimum bias collision events in Pb–Pb collisions at  $\sqrt{s_{NN}} = 2.76$  TeV shown by open circles [23]. The star markers represent the Weibull-Glauber model.

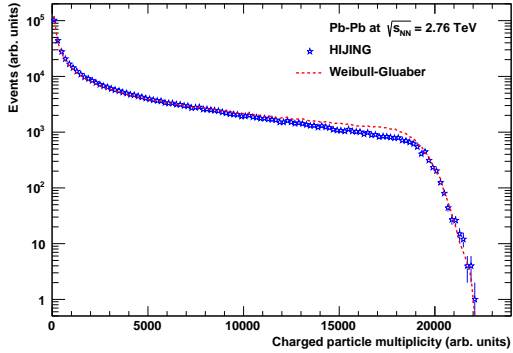


FIG. 5. (Color online) The charged particle distribution obtained from HIJING for Pb–Pb collisions at  $\sqrt{s_{NN}} = 2.76$  TeV is shown by blue line. The distribution is compared with the Weibull-Glauber model represented by red line.

ity class to study various physics observables as a function of centrality or impact parameter and to compare the same with different energies of various heavy-ion experiments.

To determine the centrality classes, the charged particle multiplicity distribution was obtained for Pb–Pb collisions at  $\sqrt{s_{NN}} = 2.76$  TeV using HIJING event generator[18]. The same was simulated using the Weibull-Glauber model. Figure 5 shows the comparison of the multiplicity distribution obtained using HIJING to the one simulated using Weibull-Glauber approach. This creates a relationship between an experimental observable and the phenomenological model of particle multiplicity in nucleus-nucleus collisions us-

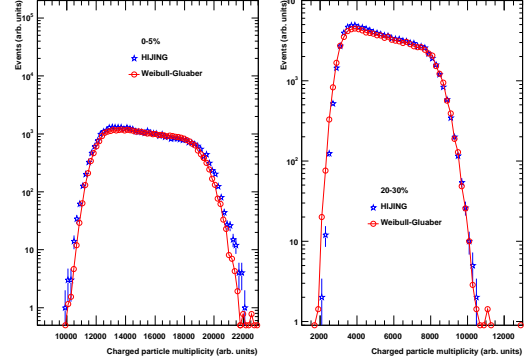


FIG. 6. (Color online) The charged particle distribution for different centralities obtained from HIJING for Pb–Pb collisions at  $\sqrt{s_{NN}} = 2.76$  TeV is shown by blue line. The centrality distributions are compared with the Weibull-Glauber model represented by red markers.

ing Weibull-Glauber approach. A given centrality class, defined by sharp cuts in the geometrical properties (like  $N_{part}$ ,  $N_{coll}$ , impact parameter( $b$ ), etc.) in the HIJING multiplicity distribution corresponds to the same centrality class obtained using Weibull-Glauber model. Now one can estimate the mean number of participants,  $\langle N_{part} \rangle$  and the mean number of binary collisions,  $\langle N_{coll} \rangle$ , for a given centrality class by applying sharp cuts in impact parameter in the generated multiplicity distribution by Weibull-Glauber approach. The values of  $\langle N_{part} \rangle$  and  $\langle N_{coll} \rangle$  obtained from the model is compared with the previously retained values from HIJING. This is shown in Table I. One can observe that the values obtained from the model and the HIJING are in close agreement with each other. Figure 6 shows the good agreement between the multiplicity distribution obtained using HIJING to the one simulated using Weibull-Glauber approach for two different centrality classes. Hence, one can use this method to determine the approximate value of  $\langle N_{part} \rangle$  and  $\langle N_{coll} \rangle$  for a given centrality class, for a given collision system and energy.

## V. SUMMARY

The charged-particle multiplicity and transverse energy distributions in heavy ion collisions at RHIC and LHC energies are well described by the two-component Glauber approach using the Weibull model of particle production. We have

TABLE I. Values of  $N_{part}$  from HIJING and  $N_{part}$  from the Glauber-Weibull model for Pb–Pb collisions at  $\sqrt{s_{NN}} = 2.76$  TeV

Centrality (in %)	$b_{min}$ (fm)	$b_{max}$ (fm)	$N_{part}$ (HI- JING)	$N_{part}$ (Model)
0 - 5%	0	5.0	364.7	354.9
20 - 30%	6.6	10.8	144.6	144.0
50 - 60%	11.0	13.8	34.01	34.24
70 - 80%	13.6	18.6	6.052	6.713

demonstrated that the Weibull-Glauber approach can be used to determine the centrality classes of heavy-ion collision at a given energy. This is particularly significant regarding the applicability of the Weibull distribution to characterize the system created in heavy ion collisions.

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